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Report for LANSCE Futures Spring 2021 Workshop Series

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Purpose of the LANSCE Futures Workshops:

The Los Alamos Neutron Science Center (LANSCE) has a long and successful history of delivering high-impact science for NNSA missions. The breadth of science LANSCE delivers is enabled by a unique combination of beam power, flexibility, and authorization basis. Though LANSCE is entering its 50th year of operations, current plans for the stockpile require LANSCE capabilities beyond 2050. These requirements demand a technical conversation about the accelerator and the long-term scientific vision for the facility, so we convened a set of workshops to initiate that conversation.

The LANSCE Futures workshops spanned three capability areas of LANSCE: dynamic radiography, scattering science, and nuclear science. Participants included the relevant experts from the programs sponsoring LANSCE, the experimentalists utilizing the end-stations, and accelerator systems experts. A final workshop combined the three focus areas to begin the conversation about capabilities that could meet future mission needs.

A phased approach is needed to meet short- and long-term needs for the accelerator and experimental end station capabilities. The first required phase is driven by the need to modernize the accelerator components that are most at risk to improve reliability and the accelerator lifetime. This phase will include the reversal of deferred maintenance, the replacement of end-of-life components, and a proposed ~\$300M capital investment – the LANSCE Modernization Project (LAMP). The next phase is improving and expanding experimental end station capabilities on the near, intermediate, and farther time horizons. Near-term concepts are small-scale investments that can be pursued with ongoing programmatic funds. The intermediate phase is the LANSCE Enhancements (LANE) concept for a portfolio of mid-scale investments spanning several experimental areas that would bring more significant upgrades to LANSCE starting in the late 2020s. The longer-term concepts leverage LAMP and LANE and represent the most significant investments in LANSCE Futures. This cumulative investment was considered from a technical feasibility viewpoint in the workshops, and the recommendations from the workshops for LANE and other investments are made within this broader context.

Summary of the LANSCE Futures Workshops:

A summary of the workshops held is shown in Table 1.

Name	Conveners	Dates	Attendees
Dynamic Radiography	M. Freeman and K. Prestridge	April 5 – 6, 2021	>100
Scattering Science	S. Vogel and D. Brown	April 21, 2021	60
Nuclear Science	H. Y. Lee and S. Mosby	May 10 – 11, 2021	80
Area A	D. Gorelov and S. Mosby	June 1 – 2, 2021	25

Table 1: statistics for the LANSCE Futures Workshop Series

The first three workshops used technical, program, and facility representatives from key partners to narrow down a large concept space into a subset that was the most programmatically relevant and technically viable. The final workshop began a cross-discipline conversation about how those concepts might be implemented most effectively [1-6].

While LANSCE is a user facility that serves multiple sponsors, the workshops primarily addressed NNSA-relevant topics while capturing the concepts for non-NNSA sponsors that might potentially impact NNSA concepts. The most significant include a concept for a Fusion Prototypic Neutron Source (FPNS) serving radiation effects for Fusion Energy Sciences, and a concept for a high-power Ultra Cold Neutron (UCN) source serving the National Science Foundation and DOE's Office of Science. These concepts require an understanding of how NNSA and non-NNSA stakeholders interact for the future of LANSCE, and the LANSCE Facility Director (LUFD) is encouraged to facilitate discussions with these programs.

The concepts that best meet NNSA mission needs are summarized in Table 2.

Discipline	Dynamic Radiography	Scattering Science	Nuclear Science
In progress / shorter timeline	<ul style="list-style-type: none"> • Multi-pulse x-ray source • Pu@pRad • High resolution framing cameras 	Vault-type room for classified experiments	<ul style="list-style-type: none"> • Mk IV Lujan Target • Short-lived isotope production and study at WNR and Lujan
Medium and intermediate timeline (smaller investments and LANE)	<p>pRad beamlines and capabilities:</p> <ul style="list-style-type: none"> • H⁺ beam • New beamlines • Actinide capabilities on Gun/PHELIX • Microscope (x21) • Fast detectors 	Develop additional Lujan flight paths for scattering and/or radiography	<ul style="list-style-type: none"> • Initial use of low-power protons in Area A • Enhanced isotope production and separation
Longer timeline (2030+)	<ul style="list-style-type: none"> • 3-5 GeV pRad • Multi-probe pRad with complementary light source 	Compact x-ray source	<ul style="list-style-type: none"> • Neutron target • Burst facility

Table 2: summary of concepts resulting from the LANSCE Futures Workshop Series

These concepts generally converged around a central question and technical limitation of current capabilities and are summarized as follows.

Dynamic Radiography: “How do we make pRad data more constraining for hydrocode and model validation?”

Proton radiography is used to address a range of focused experiments toward understanding dynamic material behavior. The current capability is limited by proton energy and the single beamline for all pRad experiments. The 800 MeV beam energy limits both the scale of

experiments and the size of features that can be observed. The current pRad capability is adding improvements to diagnostics with multi-pulse x-ray sources, and the resumption of plutonium experiments in 2024.

The mission need for pRad is to maintain the ability to perform intermediate-scale explosive experiments (including with Pu), with a new ability to resolve meso-scale density and velocity changes while simultaneously observing bulk stochastic material behaviors in dense materials. These mission needs translate to higher resolution, transmission and dynamic range needed in a large field of view (FOV), for example, within the pRad “Identity Lens” 120 mm FOV. The oversubscription of the single pRad beamline will be exacerbated by the addition of plutonium experiments to the run cycle when Pu@pRad comes online in 2024. Additional pRad beamlines are needed to support the current experimental cadence and the broad range of drivers demanded by the NNSA program community, e.g., explosives, guns, and pulsed power.

Investments via LANE could improve pRad’s resolution and experimental throughput in the shorter-term by delivering H^+ proton beams and adding beam lines. H^+ protons have better ion source intensity than the H^- protons currently utilized by pRad, with lower emittance. Both of these features ultimately drive resolution, and as LANSCE already accelerates both species, this objective is achievable on intermediate timelines and budgets. With additional beamlines and H^+ protons, significant development of high-speed scintillators and imaging systems could occur, paving the way for longer-term improvements in the capability. This development could occur in parallel with multiprobe diagnostics, such as an additional light source for pRad experiments that leverages the current pRad x-ray work, with potential sources such as an electron linear accelerator, an advanced Febetron, or a multi-pulse laser under consideration.

In the longer term, higher energy pRad provides an opportunity to meet the mission need of maintaining a large field of view while increasing spatial resolution and contrast. A 3 – 5 GeV pRad will require a significant accelerator investment, but it would allow improvements in resolution from 300 μm to 10 μm while maintaining the large field of view necessary for explosively-driven pRad experiments. Multiple accelerator solutions are possible to achieve energy-upgraded pRad: (1) A high-gradient linear accelerator fed by the main LANSCE accelerator takes advantage of ongoing R&D within the accelerator division, but does not yet meet pRad’s multi-pulse requirements and therefore is considered to be low TRL. (2) A superconducting booster was considered in 2012 [7], where relevant technology has been demonstrated at the Spallation Neutron Source (SNS) at Oak Ridge. While this option is considered to be high TRL (7 or greater), the interaction and consequences for beam delivery to other LANSCE beam lines are not yet fully understood. (3) Finally, a proton synchrotron is considered to be a high TRL solution that would meet pRad’s multiple pulse requirements, possibly with less flexibility than the superconducting booster. Down selecting among these options will require further effort to understand the potential cost and risk vs performance of each as well as their interactions with beam delivery elsewhere at LANSCE. Each of these solutions will require the advanced detector development enabled by the addition of pRad beamlines at LANSCE to ensure that timing and spatial resolution requirements are met.

Scattering Science: *“What tools are needed to address Advanced Manufacturing and Aging?”*

LANL’s scattering science community utilizes neutrons and x-rays to characterize materials of interest to advanced manufacturing and aging. The mission demands on this program have driven it towards energy-resolved neutron imaging, but the current beamlines do not adequately support this requirement due to background rates. Enhancements to neutron scattering capabilities are being implemented to meet mission needs, including creating a permanent limited area for classified experiments.

In the intermediate future, the top priorities are to provide optimized collimation for background reduction to existing Lujan flight paths, and to stand up a dedicated neutron imaging capability. Longer term, a compact x-ray source stationed at LANSCE and based on Inverse Compton Scattering (ICS) could provide the technical solution to experimental throughput and authorization basis issues currently encountered at other facilities, such as the APS at Argonne National Laboratory. The APS provides extremely luminous x-ray beams at the cost of being a large facility with a lower experimental cadence, but the luminosity is not required for many of the NNSA-relevant measurements. LANSCE already possesses the authorization basis to conduct the relevant hazardous and/or classified measurements, such that significant gains in both the breadth and total throughput of experiments would be realized by having the ICS source stationed at LANSCE.

Nuclear Science: *“How do we constrain the nuclear reaction networks involved in weapons?”*

The mission need for nuclear science is clear – to inform neutron reactivity, radiochemical diagnostics, and radiation effects. Neutron reactivity helps determine weapons performance, and the data are essential for accurate safety/criticality assessments of subcritical experiments. There are multiple mission needs to reduce uncertainty or acquire data on nuclear reaction rates, a key parameter in determining neutron reactivity [8,9]. High neutron fluence environments, such as those measured via radiochemical diagnostics, can transmute stable isotopes to unstable ones, and many of the nuclear reaction rates on unstable isotopes have not yet been measured experimentally [10,11]. Understanding component performance in extreme environments requires experimental measurements of radiation effects on materials.

In the short term, improvements to the Weapons Neutron Research (WNR) and Lujan Center experimental areas have begun to address the open questions in nuclear science. At the Lujan Center, the Mk IV spallation target is being installed in CY22 to deliver increased neutron flux at the relevant energies. The neutron beams will be better characterized to reduce reported experimental uncertainties. First generation radioisotope measurements are being developed at WNR and the Lujan Center.

In the intermediate future, an isotope separator is required to deliver high-quality nuclear reaction rate data on radioactive isotopes by optimizing signal-to-background. While LANSCE’s Isotope Production Facility (IPF) can perform chemical separations, several technical solutions exist that could provide the new, required isotope separation capability. Work has begun on a set of benchmark experiments and target purities to drive the selection of separator technology for potential integration with the LANE investment. With a low-power proton beamline dedicated to radiation effects, the national demand for studies of charged-particle induced failures can be met.

Longer term, the technical goal for radiochemical diagnostic science is the “neutron target” concept. The ultimate limit of traditional nuclear reaction rate experiments comes from shining a neutron beam on a stationary sample. For the very short-lived cases, the sample either decays before a credible experiment can be fielded, or the extreme radiation field produced by the sample destroys the necessary detectors. A neutron target concept turns this picture around by creating a standing field of neutrons within a spallation source and moderator/reflector assembly, and circulating a beam of radioactive ions through that field to perform the necessary measurements [11,12]. A proof-of-principle experiment has been proposed to demonstrate the necessary technical integration to realize such a capability.

Conclusions and recommendations toward LANE:

Long-term development paths for radiography, scattering, and nuclear science that meet NNSA mission needs are outlined in detail in the LANSCE Futures workshop reports. To make progress toward these goals, there are multiple intermediate solutions that are recommended for LANE investment.

Dynamic Radiography

1. Develop a plan for additional pRad beam lines outside of Area C, including H⁺ beam development.
2. Perform cost, risk, and performance analysis of technical approaches for a 3 – 5 GeV pRad capability.
3. Define mission-driven experiments to guide concept development toward multiprobe and higher energy pRad.

Scattering Science

1. Develop mission-need experiment to set flight path requirements.
2. Define requirements for the compact x-ray source.

Nuclear Science

1. Complete plan for WNR optimizations and flight path upgrades.
2. Develop benchmark requirements for the radioisotope separator and perform proof-of-principle experiment for the “neutron target” concept.
3. Collaborate with pRad community on the return of protons to Area A and technical assessment of a 3 – 5 GeV proton synchrotron for both radiography and acute radiation effects studies.

LAMP Coordination

Technical solutions for LAMP should not preclude – and, ideally, should enable – any of the concepts under development for LANE and beyond. Therefore, LAMP should create a formal scientific liaison to ensure appropriate communication between the scientific and accelerator design communities. Continued development of both LAMP and LANE requires resources and broad coordination that should be organized through the Accelerator Strategy Office (ASO) reporting to LUFU.

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